CHARACTERIZATION AND PERFORMANCE ANALYSIS OF MULTI-STACK VANADIUM REDOX FLOW BATTERY

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Teknologi penyimpanan tenaga adalah teknologi yang menguruskan sistem bekalan kuasa elektrik demi menjana tenaga dan penjimatan kos bagi syarikat pengeluar utiliti dan pengguna. Kuasa angin, solar, dan kuasa hidroelektrik adalah diantara contoh sumber yang boleh diperbaharui dan ianya digunakan sebagai tenaga alternatif dan tenaga simpanan untuk bekalan kuasa elektrik. Bateri Aliran Redoks (RFB) adalah sistem elektrokimia yang boleh menukar dan menyimpan tenaga berulang kali dalam skala yang besar. Bateri Aliran Redoks Vanadium (VRFB) adalah salah satu teknologi penyimpanan tenaga yang perlu diberikan perhatian disebabkan oleh keupayaannya menyingkir masalah percampuran elektrolit yang berlaku dalam kalangan Bateri Aliran redoks yang lain. Berkongsi prinsip yang sama untuk menyimpan tenaga luaran seperti sel bahan bakar, RFB mempunyai kelebihan iaitu membalikkan tindak balas elektrokimia dalam sel secara elektrikal. Baru-baru ini, banyak penyelidikan mengenai VRFB telah difokuskan di bawah ujian lapangan, peringkat demonstrasi dan penyiasatan masalah – masalah kebocoran oleh getah disekeliling sel, membran, bahan karbon dan pemasangan didalam pembinaan sel, tetapi maklumat mengenai pembinaan sel , pencirian eksperimen, penyediaan elektrolit, dan sistem keseluruhan di bawah kajian masih minima. Projek ini memfokuskan kepada pencirian dan analisis prestasi untuk linierasi VRFB oleh saiz permukaan sel yang berbeza iaitu 25 cm^2, 56.25 cm^2 dan 100 cm^2. Prestasi unit sel berkenaan dengan kecekapan voltan di bawah parameter yang berbeza (kepadatan arus elektrik, kadar aliran elektolit, jumlah elektrolit, suhu sel, keliangan elektrod dan kekonduksian membran) dibentangkan bersama dengan penentuan linearasi sel sambil mengekalkan kecekapan coulombik pada nilai optimumnya iaitu 90%. Sel yang berbeza saiz permukaan mempamerkan ciri – ciri yang berbeza di bawah operasi parameter yang berbeza. Reka bentuk sel terbaik untuk projek ini adalah bagi saiz elektrod 100 cm^2 pada ketumpatan arus elektrik 50 mA/cm^2, kadar aliran elektrolit 0.17 cm^3/s, jumlah elektrolit 10 cm^3, suhu sel 288.15 K, keliangan elektrod 0.94 epsilon dan konduktiviti membran sebanyak 15 S/m. Hubungan antara saiz elektrod VRFB yang pelbagai dianalisis dan dibincangkan untuk mencipta teori-teori bagi linearasi di mana kajian mendapati bahawa terdapat hubungan linear antara ketumpatan arus elektrik, kadar aliran elektrolit, suhu sel dan nilai keliangan elektrod dengan saiz sel yang sama manakala tiada hubungan linear antara jumlah elektrolit dan nilai kekonduksian membran dengan saiz sel yang sama. Akhir sekali, cadangan untuk penambahbaikan sistem dibincangkan.

ABSTRACT

Energy storage technology is a technology that manages power supply system to create energy and cost saving for utilities and consumers. Wind power, solar, and hydroelectric power are examples of renewable resources and are used as an alternative energy and energy storage for power supply. Redox Flow Battery (RFB) is an electrochemical system that could repeatedly convert and store energy in large scale. Vanadium Redox Flow Battery (VRFB) is one of the noteworthy energy storage due to the fact that it eliminates the cross contamination of electrolyte problem that occurs in other redox flow battery. Sharing the same principle of storing the energy externally as fuel cells, RFB has the advantage of being able to electrically reverse the electrochemical reaction within the cell. Much of the emphasis of recent research on vanadium redox flow battery (VRFB) has been focused under field testing, demonstration stage and the investigation of leakage problem caused by rubber seal, membrane, carbon felt and fitting in construction, but information on construction, experimental characterization, electrolyte preparation, and overall systems under study is still minimal. This project focuses on the characterization and performance analysis for linearity of a multi-stack VRFB for different cell stack sizes of 25 cm^2, 56.25 cm^2 and 100 cm^2. The unit cell performance with respect to voltage efficiency under different performance parameters (current density, flow rates, volume of electrolytes, temperature of cell, electrode porosity and membrane conductivity) are presented along with the cell linearity findings while keeping the coulombic efficiency at its optimum value of 90%. The cell stack exhibits different characteristics under different operating parameters. The best cell design for this project is for the electrode size of 100 cm^2 at current density of 50 mA/cm^2, flow rate of 0.17 cm^3/s, electrolyte volume of 10 cm^3, cell temperature of 288.15 K, electrode porosity of 0.94 epsilon and membrane conductivity of 15 S/m. The relation between the size of electrodes in multi-stack VRFB is also analysed and discussed to develop theories for linearity in which it is found that there exists a linear relationship between different current density, flow rate, temperatures of cell and electrode porosity value with the same cell stack size but no linear relationship between different volume of electrolytes and membrane conductivity values with the same cell stack size. Ultimately, suggestion for system improvement is highlighted.

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LIST OF SYMBOLS

mA/cm^2	Mill ampere / square centimetre
cm^3/s	Cubic centimetre / second
cm^3	Cubic centimetre
K	Kelvin
S/m	Siemens / metre
W/cm^2	Watt / square centimetre

LIST OF ABBREVIATIONS

VRFB	Vanadium redox flow battery
EIA	Energy Information Administration
IEO2013	International Energy Outlook 2013
RFB	Redox flow battery
DOD	Depth of discharge
UNSW	University of New South Wales
GW	Gigawatt
SMES	Superconducting Magnetic Energy Storage
LA	Lead Acid
NaS	Sodium Sulphur
Li-ion	Lithium ion
Zn-Br	Zinc Bromine
SOC	State of Charge
MATLAB	Matrix Laboratory
ODE	Ordinary Differential Equations
RK	Runge – Kutta
DAE	Differential Algebraic Equation
EIS	Electrochemical Impedance Spectroscopy
MSA	Measurement System Analysis
PEMFC	Proton Exchange Membrane Fuel Cells

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